Design And Test of Prototype Cavities For The ELFA Linac

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Abstract

The design study of two possible configurations for the ELFA linac are presented. The first one is a multicell SLAC-type structure scaled down to 1300 MHz, the operating frequency of ELFA. The second one is a multicell standing wave structure similar to the one foreseen for the Tesla project. The effect of the input and output couplers on the beam dynamics in the Travelling Wave is carefully studied by computing the fields of the whole structure (including the couplers) by using the HFSS electromagnetic solver developed by Hewlett-Packard. Last the computed dispersion relation for the model structure is compared with the measured one of a prototype structure.

I. INTRODUCTION

ELFA (Electron Laser Facility for Acceleration) is a high-gain free electron laser designed to operate in the microwave region (radiation wavelength = 3 mm) with goals that are both fundamental and technological in nature [1]. Among the basic features of the ELFA experiment there is an RF linac to provide electron beams with characteristics sufficient to drive a free electron laser amplifier at 30-100 GHz in the high gain regime in the presence of strong space charge forces. The accelerator should deliver a 50 A peak current electron beam at 6 MeV, with low emittance. The principal performance parameters required for the ELFA accelerator are reported in [2].

The choice of an operating frequency of 1.3 GHz for the RF structure allows to fit the need of a train of several micropulses with small energy spread.

II. LINAC DESIGN STUDY

Two possible configurations for the ELFA linac are considered. The first one is a SLAC-type 6 cavity section, operating at 1.3 GHz in a travelling wave $2\pi/3$ mode to maximize the shunt impedance; the second one is a standing wave section of 4 cavities operating in the π mode. For the latter approach we have been studying a structure similar to the one foreseen for the TeV Superconducting Linear Accelerator (TESLA).

A. Standing wave structure.

A four cell structure was chosen to have two complete accelerating periods in the π mode at 1300 MHz. The results of the 2D calculations are summarized in Table 1.

Table 1.
Characteristics of the SW accelerating structure.

Structure length, L	65 cm
Frequency, f	1301.4 MHz
Stored energy, U	9 J
Energy gain, V	6 MeV
Transit time factor, T	0.69
Power loss, P	2.5 MW
Peak surface electric field	33.5 MV/m
Peak axial electric field	24.9 MV/m
Shunt impedance, V^2/P	14.1 MΩ
Quality factor, Q	$3\ 10^4$

The structure shape and the axial electric field are shown in figures 1 and 2.

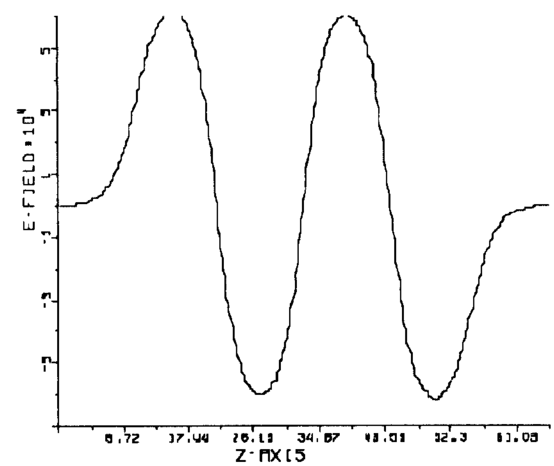

Figure 1. SW axial field.

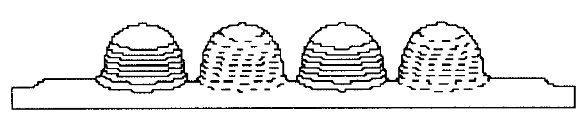

Figure 2. SW accelerating structure.

B. Travelling wave structure.

The results of the 2D calculation for one period of the TW structure are presented in Table 2. The same normalization condition was chosen as for the SW case.

The cavity shape and axial electric field are shown in fig. 3 and 4.

A 3D calculation of the TW structure, scaled to 3000 MHz, including the input and output power couplers was also performed. Due to the very short length of the structure the presence of the power couplers can severely modify the field distribution. In particular an accurate calculation of the fields in the first cell of the structure (that is in the low β section) is needed to fulfil the tight requirements on beam quality. To compensate for the presence of the power couplers the first and last cells of the structure were greatly modified.

The results of the 3D simulations are summarized in Tables 3a and 3b.

The cavity shape for the 3D simulation was identical to the one used for the 2D calculation, and was chosen to match the design of the NEPAL cavity at 3 GHz [3]. The first and last cells in the structure were modified to compensate for the presence of the input and output power couplers and beam tubes [4]. An outline of the full 3D structure is shown in figure 5, while the calculated axial electric field is shown in figure 6.

For the 3D calculation the High Frequency Structure Simulator (HFSS) code from Hewlett-Packard was used.

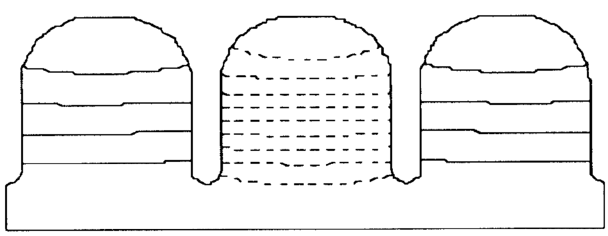

Figure 3. TW accelerating structure (one period).

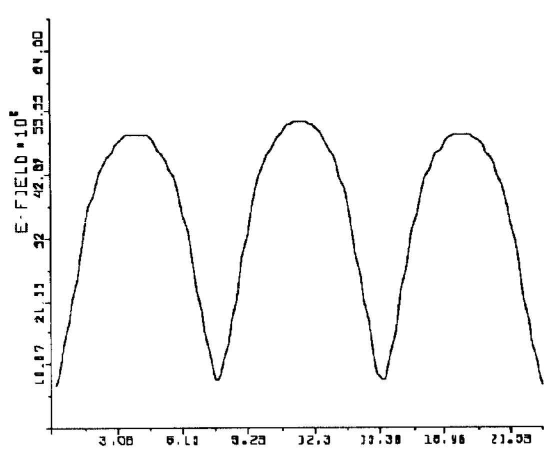

Figure 4. TW axial field (one period).

Table 2.
Characteristics of the TW accelerating structure (one period).

Structure length, L	23 cm
Frequency, f	1300 MHz
Stored energy, U	2.2 J
Energy gain, V	3 MeV
Transit time factor, T	0.79
Power loss, P	0.78 MW
Peak surface electric field	25 MV/m
Peak axial electric field	15 MV/m
Shunt impedance, V^2/P	11.5 MΩ
Quality factor, Q	2.3 10^4
Group velocity, v_g	0.6 %

Table 3a.
Results of the 3D simulations of the TW accelerating structure at 3000 MHz.

Structure length, L	28 cm
Frequency, f	3000 MHz
Stored energy, U	2.2 J
Energy gain, V	6 MeV
Transit time factor, T	0.7
Power loss, P	2.8 MW
Peak surface electric field	100 MV/m
Peak axial electric field	80 MV/m
Shunt impedance, V^2/P	12.5 MΩ
Quality factor, Q	1.5 10^4
Group velocity, v_g	0.45 %

Table 3b.
Results of the 3D simulations of the TW accelerating structure scaled at 1300 MHz.

Structure length, L	65 cm
Frequency, f	1300 MHz
Stored energy, U	5 J
Energy gain, V	6 MeV
Transit time factor, T	0.7
Power loss, P	1.8 MW
Peak surface electric field	43.5 MV/m
Peak axial electric field	34.8 MV/m
Shunt impedance, V^2/P	19.6 MΩ
Quality factor, Q	2.2 10^4
Group velocity, v_g	0.45 %

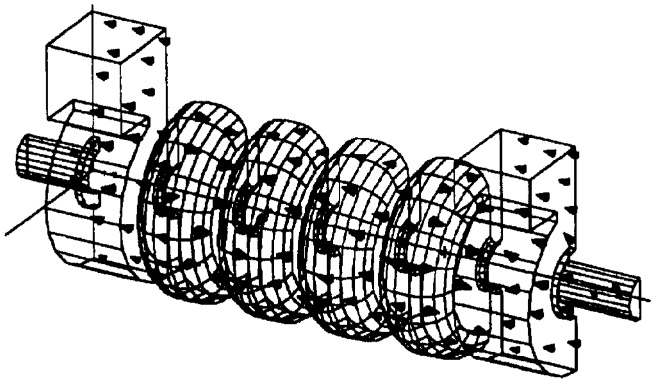

Figure 5. 3D TW accelerating structure.

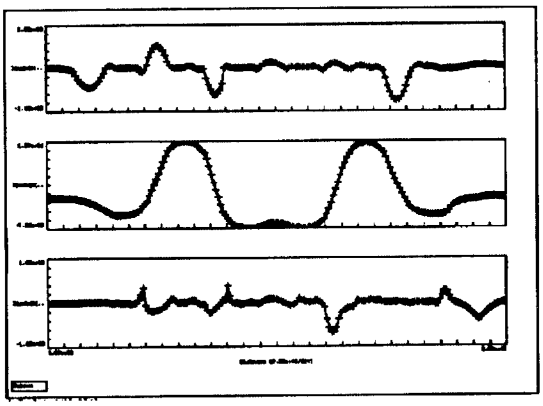

Figure 6. 3D TW structure axial field.

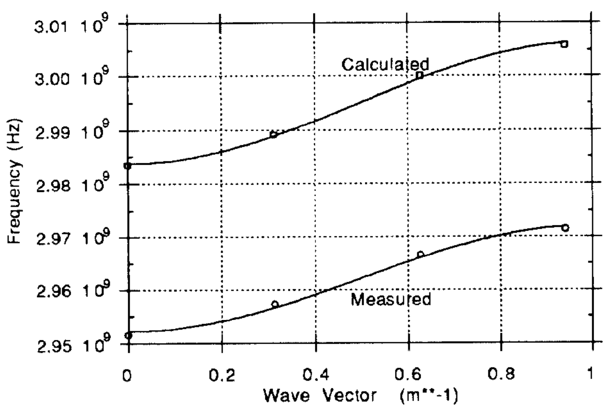

Figure 7. TW structure dispersion relation.

To verify the results of the calculation a model (scale 1:1) of the six-cell periodic structure was built. The dispersion relation of the model was measured by an HP 8510C Network Analyzer. A comparison between the measured and calculated dispersion relation is shown in figure 7.

III. CONCLUSIONS

From the calculations performed and the measurements done on the model, we can conclude that both the TW and the SW structure are suitable to fulfil the requirements on beam quality for ELFA operation using well established technologies.

Nevertheless much care must be taken in the design and realization of the TW structure, particularly with respect to the first and last cells and the power couplers, to compensate for the presence of transverse field components that can alter beam characteristics at the structure output. Furthermore much more power is needed to operate the TW structure with respect to the SW one with the same energy gain.

Due to its shortness the main drawback of the SW structure, i.e. the sensitivity to tolerances in cell realization, is much less important than it is the case for long accelerating sections [5]. In addition the presence of a single power coupler that can be positioned in a high β section reduces the problem of transverse field components compensation.

IV. ACKNOWLEDGEMENTS

We gratefully acknowledge Dr. G. Bienvenu of LAL-SERA Orsay, for giving us the drawings of the NEPAL power couplers, and for the fruitful discussions on TW accelerating structure design and realization problems.

V. REFERENCES

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